NEUROSCIENCE

Sweet Here, Salty There: Evidence for A Taste Map in the Mammalian Brain

Of all the senses, taste is the one most intimately connected to survival. Sweetness helps an animal identify energy-rich foods. Saltiness and umami—the savory flavor often associated with the food additive MSG—signal the presence of other important nutrients: electrolytes and amino acids, respectively. Bitterness can be a warning sign of toxins. But despite its fundamental importance, taste is the most poorly understood of the senses in terms of its representation in the brain.

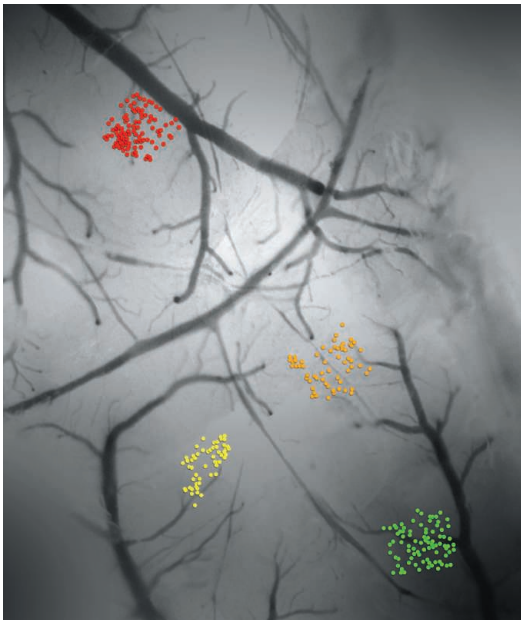
A paper published online this week in *Science* (p. 1262) presents a new picture of how taste is encoded in the mouse gustatory cortex, the region of the brain devoted to processing taste stimuli. Using sophisticated optical imaging methods to record neural activity, a team led by neuroscientist Charles Zuker of Columbia University has identified discrete clusters of neurons that respond selectively to saltiness, sweetness, bitterness, or umami. The mouse cortex, they report, contains a "gustotopic map," with each taste quality occupying its own territory.

"It really represents a breakthrough in the way we think of primary gustatory cortex," says Susan Travers, a neuroscientist at Ohio State University in Columbus. Even so, she and others say that the new results are hard to reconcile with decades of research on the neurobiology of taste that paints a somewhat more complicated picture.

Over the past decade, Zuker has shaken up the field of gustatory neuroscience. In a series of high-profile papers, his team has identified molecular sensors on cells in the tongue and palate that respond selectively to saltiness, sweetness, bitterness, sourness, or umami. The findings suggested that for each of the basic tastes there is a dedicated set of receptor cells specifically "tuned" for that taste. "This work went completely against the norm and the dogma of the time," Zuker says.

The prevailing view held that taste receptor cells are broadly tuned, much like their counterparts in the olfactory system. Individual olfactory receptor cells respond to many odors, and the activity of any given cell says little about what odor is present. But because different odors activate distinct subsets of receptor cells, the pattern of activity in a large number of cells can identify a specific odor, just as patterns of lights on a theater marquee can spell out the names of different movies, says Sidney Simon, a neuroscientist at Duke University in Durham, North Carolina.

Simon and others have argued that the gustatory system also uses this type of pattern coding. In contrast, Zuker's work pointed to a coding scheme based on neurons narrowly tuned for each basic taste quality. Such "labeled line" coding in the brain is a prominent feature in vision, hearing, and touch. In the auditory system, for example, neurons narrowly tuned for sound frequency relay signals from the cochlea to the cortex.



Mapped out. A new study finds hot spots for bitter (red), salty (orange), umami (yellow), and sweet (green) taste in the mouse gustatory cortex.

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In the new study, Zuker and colleagues investigated whether the narrow tuning they'd seen in receptor cells in the tongue extended all the way to the cortex. Using fluorescent dyes to visualize intracellular waves of calcium in active neurons, they simultaneously recorded the activity of hundreds of neurons in the gustatory cortex of anesthetized mice. When they squirted artificial saliva laced with cycloheximide, a bitter-tasting compound, onto a mouse's tongue, neurons in a small patch of the animal's gustatory cortex became active. Other bitter compounds activated the same neurons, but sour, salty, or sweet solutions did not. That suggests that neurons in this patch of cortex are selectively tuned for bitter taste but not for specific bitter compounds.

Similar experiments revealed cortical hot spots for salt, sugar, and umami. However, the researchers did not find a cluster of sour-selective neurons, perhaps, Zuker says, because it was outside the region of cortex they surveyed. The elusive sour patch notwithstanding, the findings are strong evidence for labeled lines of narrowly tuned neurons culminating in a gustotopic map in the cortex, Zuker says: "If I had to design it, there's no question that's the simplest, cleanest, tightest way to put it together."

Simon praises the study as an experimental tour de force, but he says the findings differ in several ways from what many researchers have found using older electrophysiological methods. "Most people, including myself, when we stick electrodes in gustatory cortex, we find that most neurons are broadly tuned. That is, they respond not only to sugar but also to salt, or acid [which tastes sour], or something else." One possible reason for the difference: Although much of this work has been done with unanesthetized animals, the optical imaging method used by Zuker's group requires animals to be anesthetized, which can have a significant impact on neural responses, according to Simon and others.

Some studies, however, have hinted at a gustotopic map in which neurons respond preferentially, if not exclusively, to a specific taste and in which cortical hot spots for different taste qualities overlap, says Patricia Di Lorenzo, a neuroscientist at Binghamton University in New York. The new work bolsters the evidence for a gustotopic map, Di Lorenzo says, "but it doesn't convince me there's no overlap, and it does nothing to explain the decades of electrophysiology showing broad tuning."

The failure to find a sour hot spot puzzles Travers, who says work in her lab and others has found that neurons that respond to acid are "superprevalent" at all levels of the gustatory system. Moreover, these neurons are the ones most often found to have broad tuning, responding to sodium and other ionic compounds, Travers says. "Why aren't they here? That's surprising."

"This work is really impressive, both for its technological virtuosity and its theoretical significance," says Alan Spector, a neuroscientist at Florida State University in Tallahassee. "It's going to cause a lot of discussion," he predicts. And it already has.

–GREG MILLER